UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

DEFINING ORGANIC-RICH FACIES IN THE DEVONIAN SHALE IN THE WESTERN PART OF THE APPALACHIAN BASIN

by

James W. Schmoker

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards.

INTRODUCTION

The Devonian shale section is often divided into organic-rich ("black") and organic-poor ("gray") subdivisions. In some instances, coarser grained "gray" shale may act as a reservoir and produce gas, but in the western part of the Appalachian basin the organic-rich shale facies are believed to contain the bulk of the producible gas resource. Therefore, Devonian-shale studies usually emphasize the organic-rich facies.

If drill cuttings are available for the Devonian shale sequence, the boundary between organic-rich and organic-poor facies is commonly based on the color of the shale. Other boundary definitions are based on gamma-ray wire-line logs, with the assumption that natural gamma radiation and organic content correlate. A gamma-ray intensity of 20 API units above the gray-shale baseline has been used to define the boundary between organic-rich and organic-poor facies (20-API method); a gamma-ray intensity of 230 API units has been used as the threshold value for shale of high gas content and could thus be regarded as another definition of the organic-rich, organic-poor boundary (230-API method). An organic-matter content of 2 percent by volume (0.8 percent by weight) is favored by the author as the best definition of the organic-rich, organic-poor boundary (2-percent method).

ORGANIC-FACIES BOUNDARY BASED ON SHALE COLOR

Figure 1 relates shale color to volume-percent organic content for dry samples from 46 wells located throughout the Appalachian basin. An organic-rich, organic-poor boundary of 2 percent organic-matter content by volume is equivalent to a relatively light color value between N5.5 and N6. The facies boundary picked by subsurface geologists would typically be represented by cuttings with a color value corresponding to 5 percent or more organic matter

by volume. It follows that a map of organic-rich-facies thickness defined by color, such as that of de Witt and others (1975), would show less organic-rich shale than a map based on the boundary of 2 percent organic matter by volume.

Figures 2 and 3 confirm this observation. The thickness of organic-rich Devonian-shale facies defined by the 2-percent method is shown in Figure 2. Data are from the well locations plotted in Figure 4, with organic content determined from wire-line density logs using the method described by Schmoker (1979). The thickness of organic-rich Devonian-shale facies defined by de Witt and others (1975) on the basis of the color of well cuttings is shown in Figure 3. De Witt's map is based on more data points than Figure 2 and thus shows greater detail.

Because the organic content of the shale along the western edge of the mapped area is high, there is little difference in this region in the thickness of organic-rich facies defined by the two methods. To the east, however, the thickness of organic-rich facies based on the 2-percent method (Figure 2) reaches maximums of 900-1,000 ft (274-305 m), compared to maximums of 500-600 ft (152-183 m) based on shale color (Figure 3). Although the general trends of the two maps are similar, differences in facies thickness and locations of anomalies reflect the inclusion in Figure 2 of shale with relatively light color values.

Some Devonian-shale resource-appraisal methods use as an input the volume of organic-rich ("black") sediments. It is apparent from Figures 2 and 3 that differences in the definition of the organic-rich, organic-poor boundary might lead to substantial differences in the appraisal of the natural-gas resource.

ORGANIC-FACIES BOUNDARIES BASED ON GAMMA-RAY INTENSITY

Gamma-ray methods for defining organic-rich facies are less subjective than that of color. Given a particular methodology, results should be consistent if the gamma-ray logs are corrected to uniform wellbore conditions. However, gamma-ray methods are adversely affected by two regional characteristics of the Devonian shale:

1) The shale baseline - the gamma-ray intensity if no organic matter is present - varies regionally throughout the basin.
2) The change in gamma-ray intensity per unit change in organic content varies regionally throughout the basin.

Therefore, the organic content corresponding to 20 API units above the shale baseline or to a gamma-ray intensity of 230 API units changes with location.

The organic content of Devonian shale with a gamma-ray intensity 20 API units above the baseline is plotted in Figure 5. This figure shows the minimum organic content of organic-rich facies defined by the 20-API method as a function of location in the western half of the Appalachian basin. Figure 5 (and Figure 6) are based on wire-line data from the well locations shown in Figure 4, with organic content determined using the relation between density and organic content given by Schmoker (1979).

The average organic content of shale at the organic-rich, organic-poor boundary defined by the 20-API method is about 1.8 percent by volume, but it varies along a regional trend roughly paralleling the basin axis from a low of about 1.0 percent in central Kentucky to a high of 2.6 percent in western Pennsylvania. Within the area shown, the 20-API method places more shale in the organic-rich facies than the sample-color method.

The organic content of Devonian shale with a gamma-ray intensity of 230 API units is plotted in Figure 6. This figure shows the minimum organic

content of organic-rich facies defined by the 230-API method as a function of location in the western half of the Appalachian basin.

The average organic content of shale at the organic-rich, organic-poor boundary defined by the 230-API method is about 6 percent by volume, but it varies locally from 4 to 10 percent. Within the area shown, the 230-API method is roughly comparable to that based on shale color and places significantly less shale in the organic-rich facies than either the 20-API or 2-percent methods.

Gamma-ray methods for defining organic-rich facies depend upon a covariance between gamma-ray intensity and organic content. This covariance weakens or disappears east of the limit of applicability shown in Figures 2 through 6 (Schmoker, 1979). East of this limit, gamma-ray methods for defining organic-rich facies are unreliable.

ORGANIC-FACIES BOUNDARY BASED ON ORGANIC CONTENT

The organic-rich, organic-poor boundary favored by the author is defined in terms of the organic content of the shale (2 percent by volume). The boundary value of 2 percent organic content is somewhat arbitrary, but is chosen for two reasons:

1) The minimum organic content required for significant generation of hydrocarbons in shale is about 0.5 weight-percent carbon (Tissot and Welte, 1978, p. 430), or about 1.7 volume-percent organic matter. The 2-percent boundary thus corresponds to a commonly accepted division between hydrocarbon-source and nonsource rocks.
2) Laboratory analyses of canned Devonian-shale core samples usually show a change in the relation between movable-gas content and organic content at about 2 to 3 percent organic content by volume. Movable-

gas content decreases disproportionately in rocks with less than 2 percent organic matter. The 2-percent boundary thus corresponds to a change in the resource potential of the shale.

The boundary of 2 percent organic content by volume is both quantitative and regionally invariant, and is an improvement over definitions discussed in preceding sections, provided sufficient data on organic content can be obtained. Laboratory measurements of organic content at closely spaced vertical intervals and adequate areal density are not available at present. The use of wire-line logs to calculate the organic content of Devonian shales (Schmoker, 1979) appears to be the best way to obtain adequate organic-content data in the western part of the Appalachian basin.

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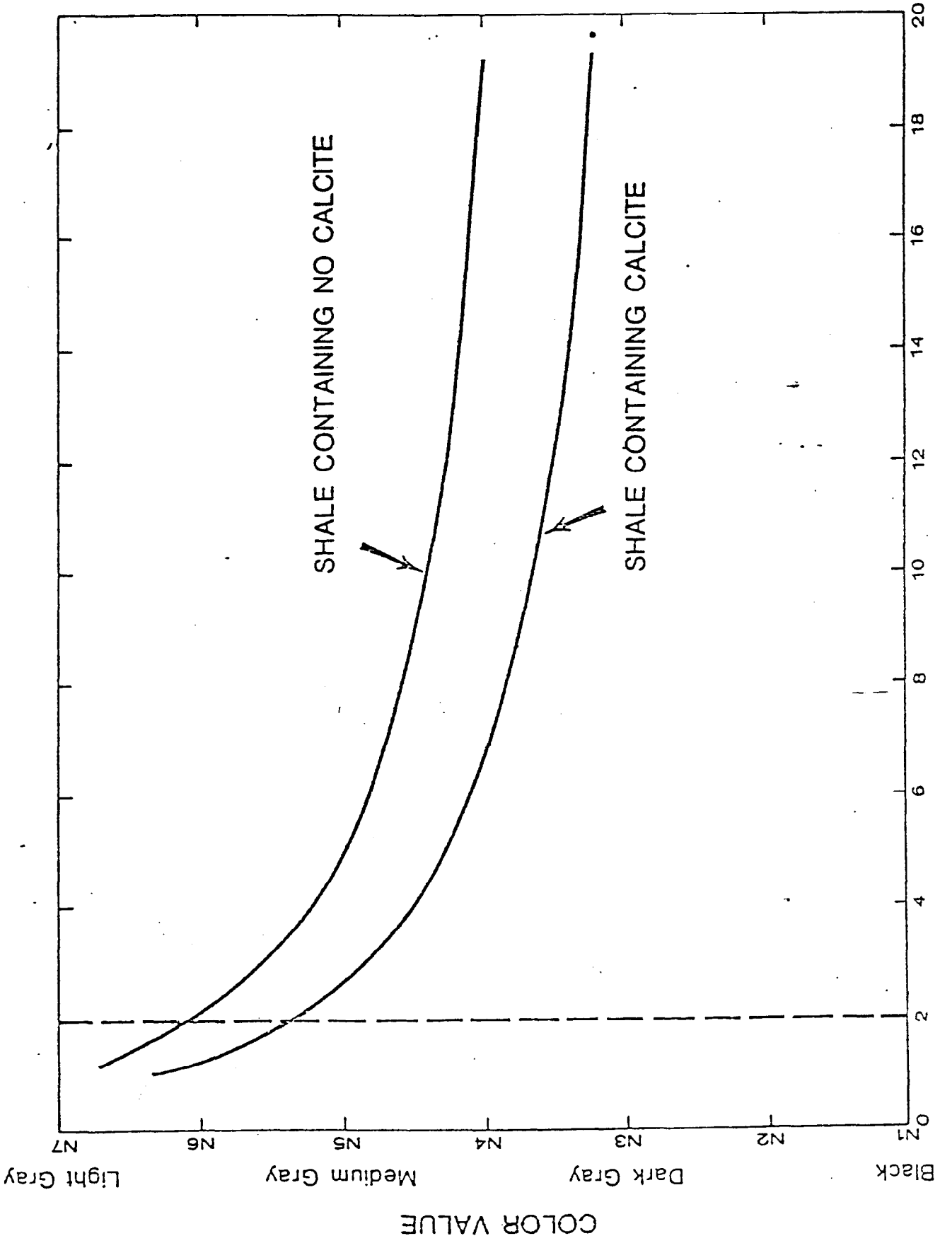

Figure 1. Devonian-shale color based on the Munsell system (Goddard and others, 1948) versus volume-percent

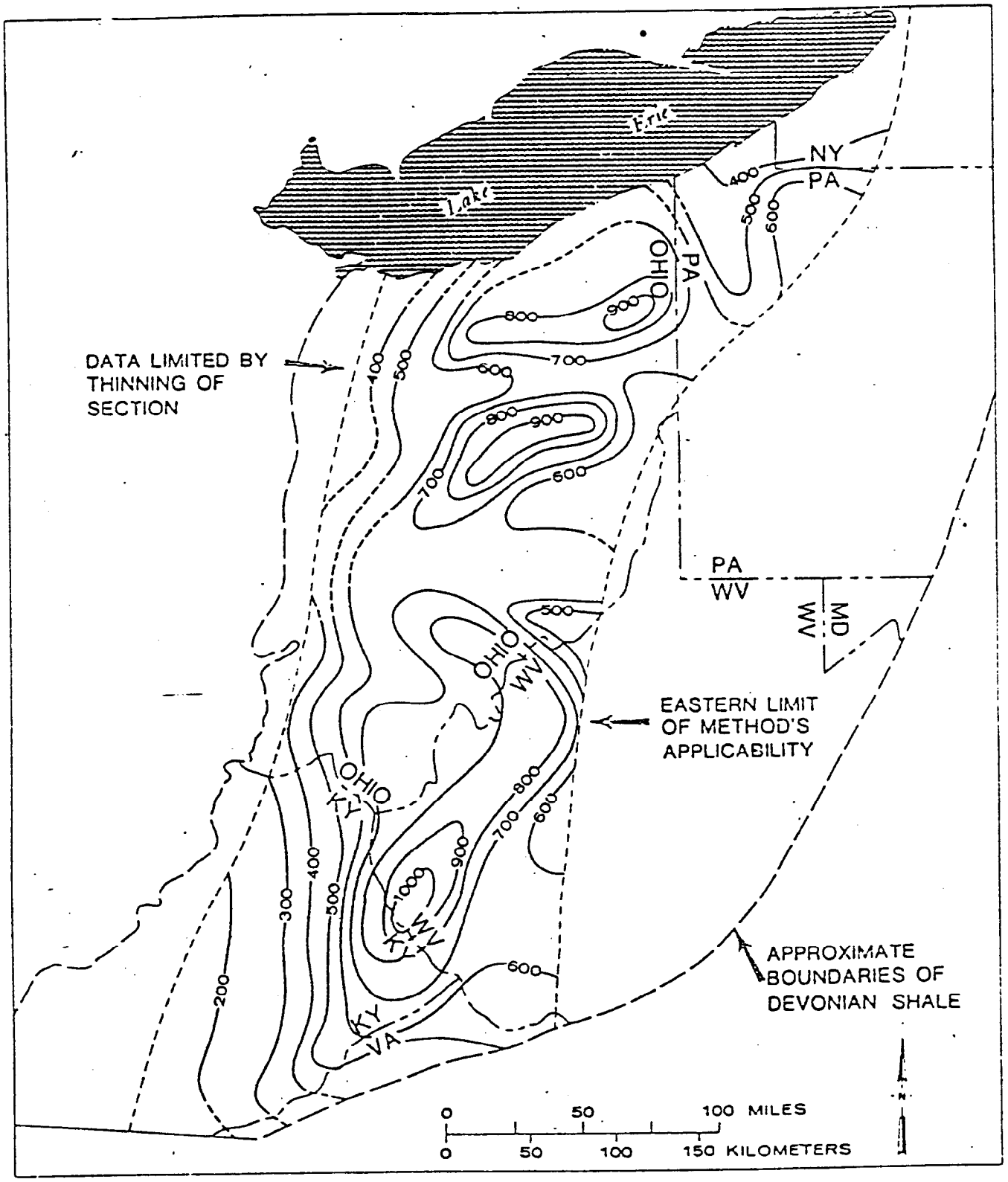

Figure 2. Thickness (ft) of organic-rich Devonian-shale facies with organic-rich defined as an organic content of 2 percent or more by volume. 1 ft = 0.3048 m. Contour interval = 100 ft.

UGR File #368
U.S.Geological Survey
1980

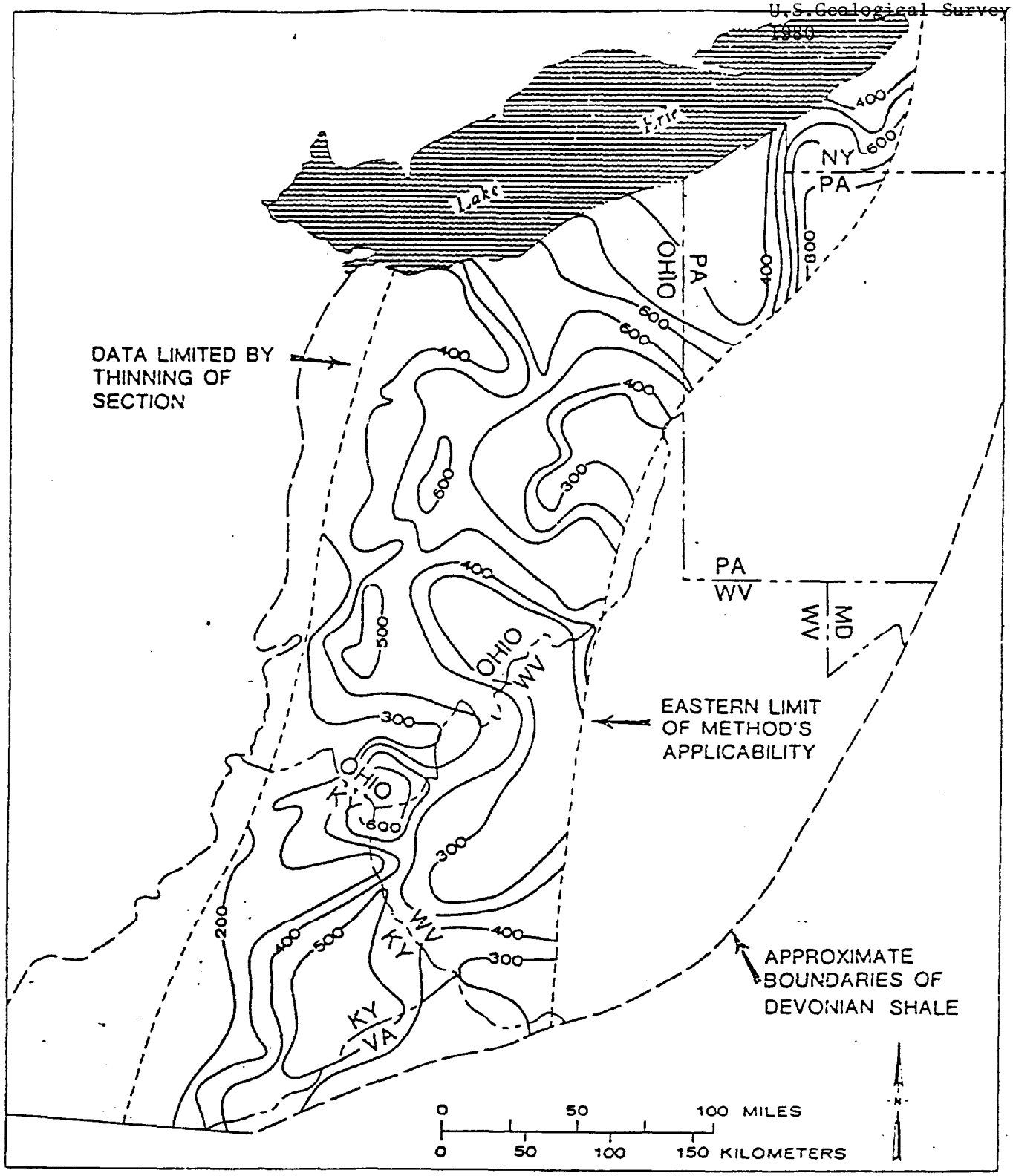

Figure 3. Thickness (ft) of organic-rich Devonian-shale facies with organic-rich defined by de Witt and others (1975) on the basis of the color of well cuttings. 1 ft = 0.3048 m. Contour interval = 100 ft.

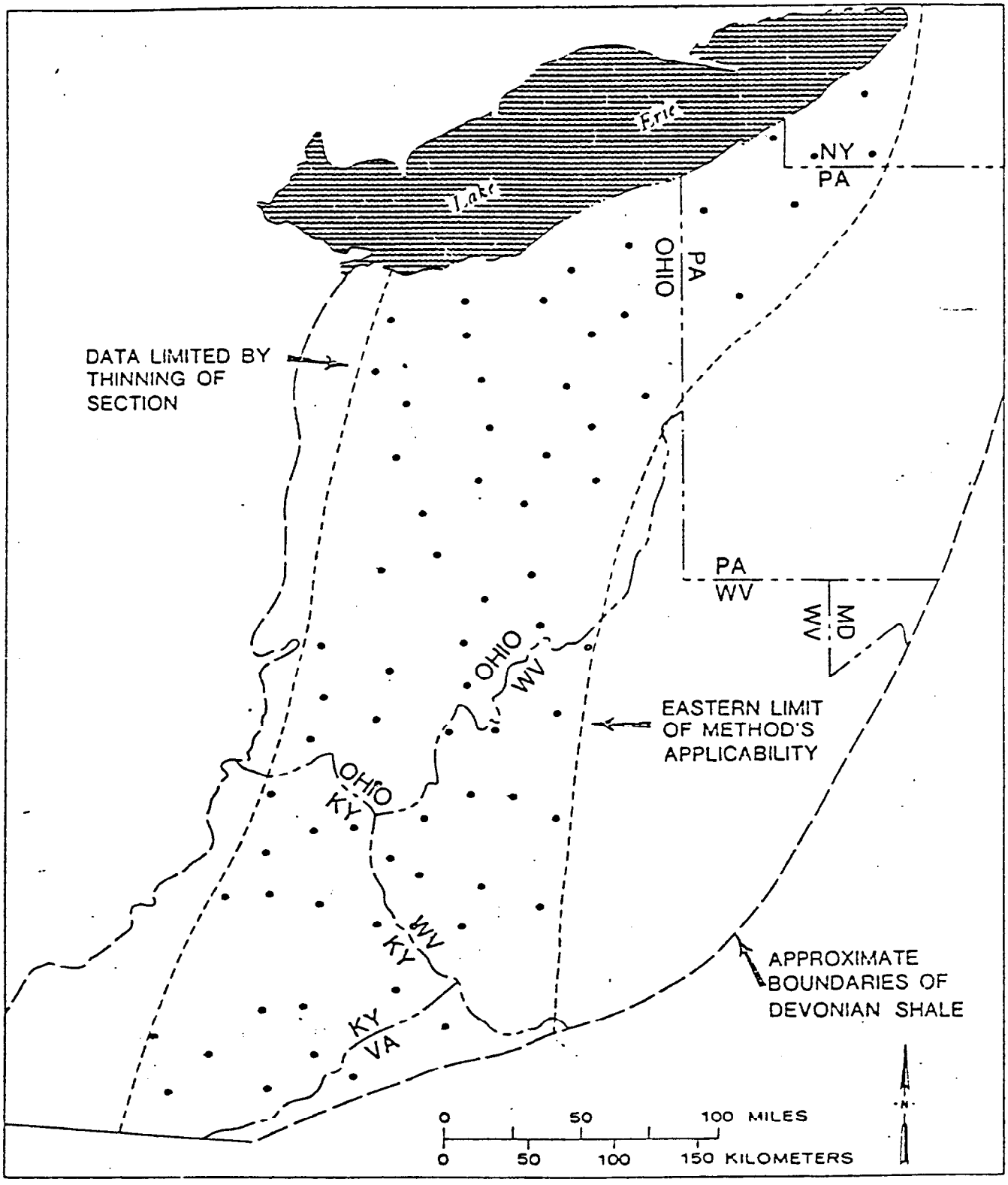

Figure 4. Locations of wells where wire-line data were obtained. The eastern limit of applicability marks the boundary of the region where gamma-ray intensity and organic content are proportional (Schmoker, 1979).

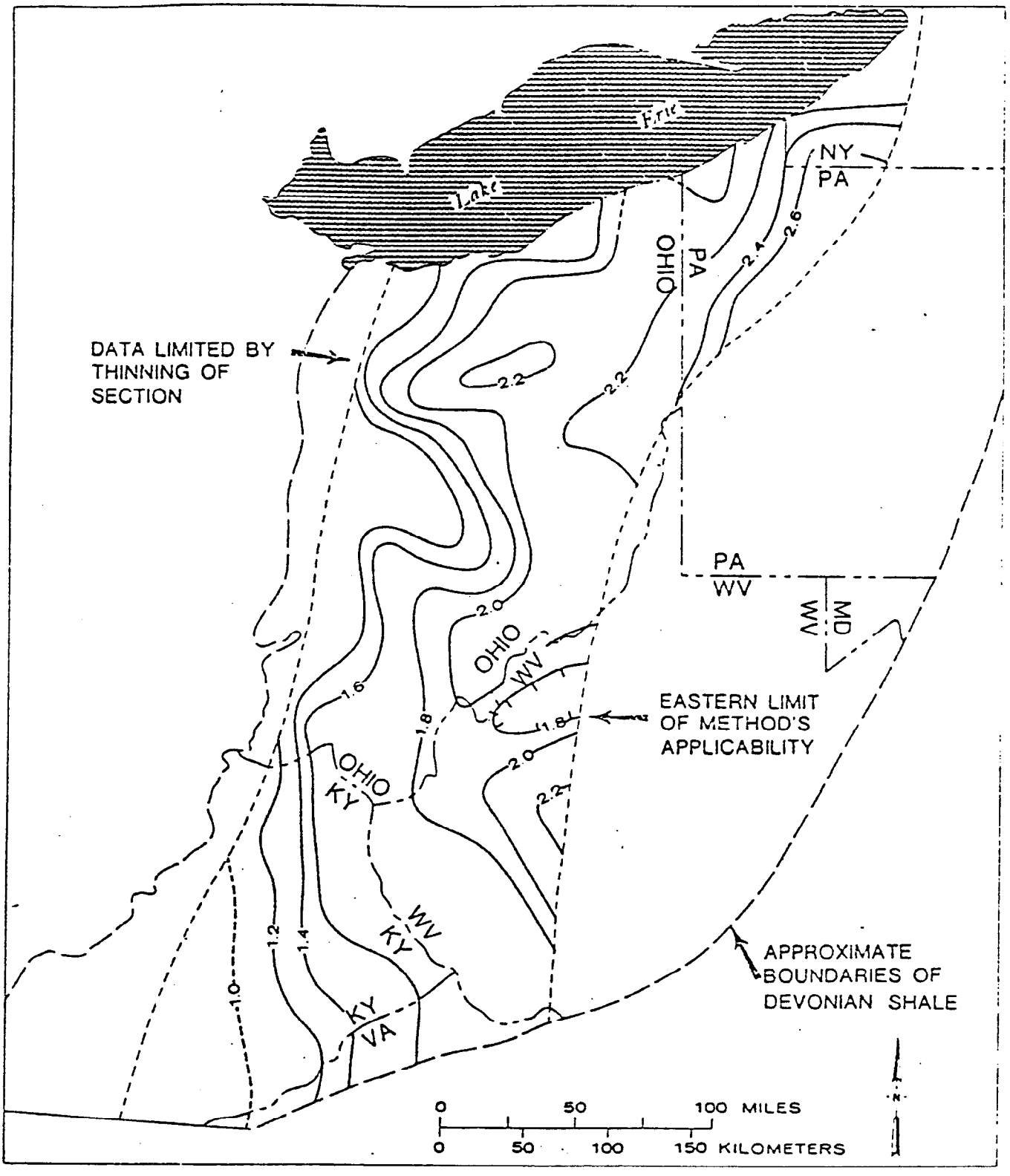

Figure 5. Organic content (volume percent) of shale with a gamma-ray intensity 20 API units above the shale baseline. Air-filled wells and a baseline corresponding to shale containing no organic matter are assumed. Contour interval = 0.2 %.

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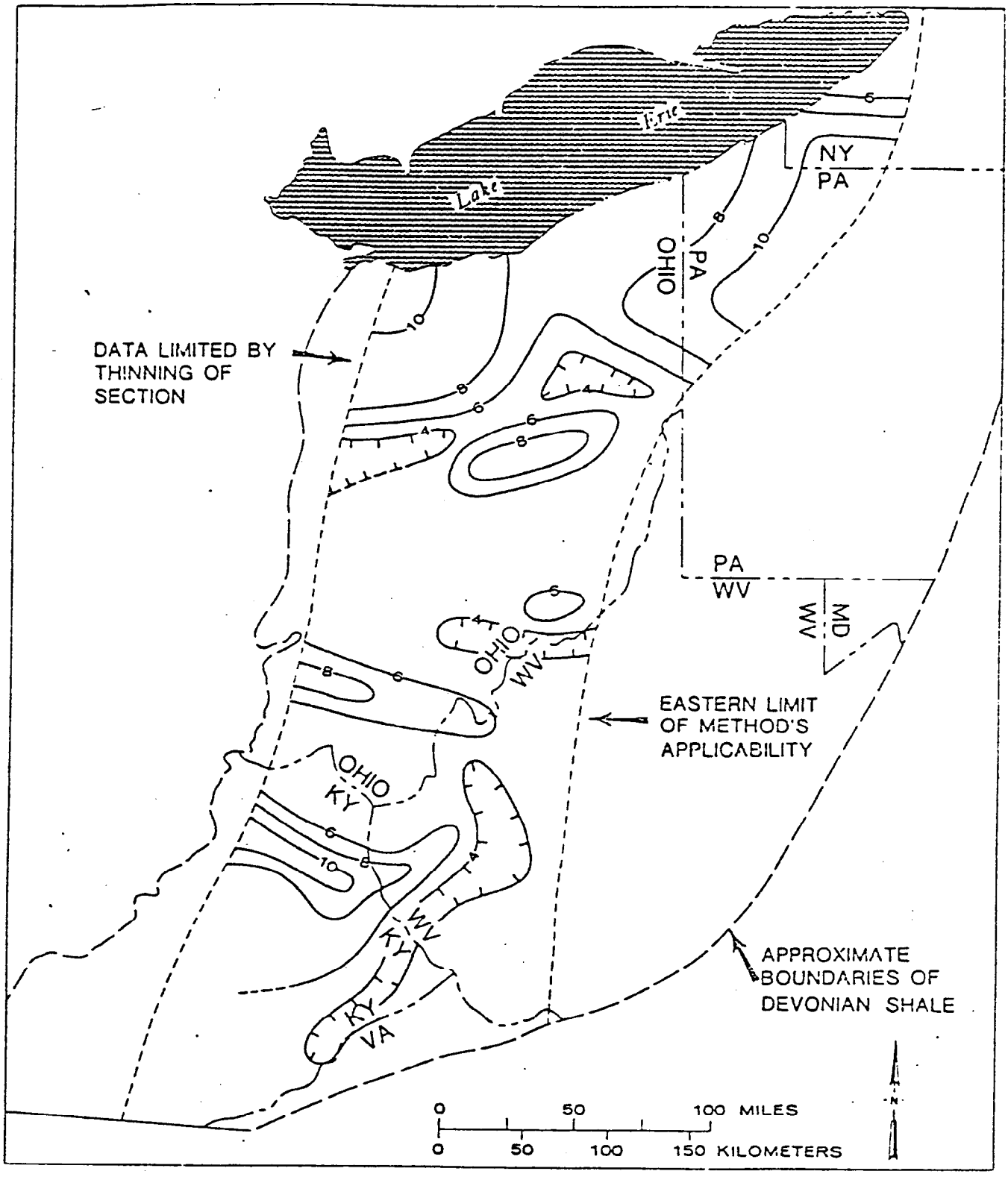

Figure 6. Organic content (volume percent) of shale with a gamma-ray intensity of 230 API units. Air-filled wells and a baseline corresponding to shale containing no organic matter are assumed. Contour interval = 2.0 %.